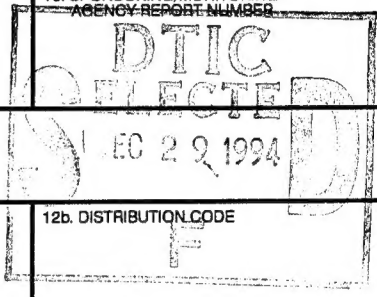# REPORT DOCUMENTATION PAGE

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A previous radio-meteorological experiment conducted along the coast of southern California showed a high correlation between UHF signals and the base of the elevated temperature inversion. A reanalysis of this experimental data with a recently developed hybrid propagation model confirmed this correlation and a method to remotely sense the refractive structure was proposed. An experiment called Variability of Coastal Atmospheric Refractivity (VOCAR) was designed under a larger program called Coastal Variability Analysis, Measurements, and Prediction. VOCAR is a multi-year experimental effort to investigate the variability of atmospheric refractivity with emphasis on the coastal zone. The experiment is being conducted by the Naval Command, Control and Ocean Surveillance Center RDT&E Division jointly with the Naval Air Warfare Center Weapons Division, Point Mugu, CA, the Naval Research Laboratory (Washington, DC and Monterey), and the Naval Postgraduate School. In addition, the National Oceanic and Atmospheric Administration Environmental Technology Laboratory, Penn State University Applied Research Laboratory, and Johns Hopkins University Applied Physics Laboratory participated in the intensive measurement phase of VOCAR. The objectives of VOCAR are to provide an assessment capability for horizontally varying refractivity conditions in a coastal environment and to develop a remote sensing capability.

The propagation measurements being made during VOCAR consist of monitoring signal strength variations of VHF/UHF transmitters in the southern California coastal region. Corresponding meteorological measurements are made during routine, special, and intensive observation periods. Measurements began in May 1993 and will be conducted periodically through 1994.

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VOCAR: An Experiment in Variability of Coastal Atmospheric Refractivity

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Abstract

A previous radio-meteorological experiment conducted along the coast of southern California showed a high correlation between UHF signals and the base of the elevated temperature inversion. A reanalysis of this experimental data with a recently developed hybrid propagation model confirmed this correlation and a method to remotely sense the refractive structure was proposed. An experiment called Variability of Coastal Atmospheric Refractivity (VOCAR) was designed under a larger program called Coastal Variability Analysis, Measurements, and Prediction. VOCAR is a multi-year experimental effort to investigate the variability of atmospheric refractivity with emphasis on the coastal zone. The experiment is being conducted by the Naval Command, Control and Ocean Surveillance Center RDT&E Division jointly with the Naval Air Warfare Center Weapons Division, Point Mugu, CA, the Naval Research Laboratory (Washington, DC and Monterey), and the Naval Postgraduate School. In addition, the National Oceanic and Atmospheric Administration Environmental Technology Laboratory, Penn State University Applied Research Laboratory, and Johns Hopkins University Applied Physics Laboratory participated in the intensive measurement phase of VOCAR. The objectives of VOCAR are to provide an assessment capability for horizontally varying refractivity conditions in a coastal environment and to develop a remote sensing capability. The propagation measurements being made during VOCAR consist of monitoring signal strength variations of VHF/UHF transmitters in the southern California coastal region. Corresponding meteorological measurements are made during routine, special, and intensive observation periods. Measurements began in May 1993 and will be conducted periodically through 1994.

INTRODUCTION

In 1944, the U.S. Navy Radio and Sound Laboratory began a radio-meteorological experiment along the coast of southern California (L. J. Anderson, 1944; D. E. Kerr, 1951). Transmitter and receiver terminals were located on the coast at San Pedro and San Diego at altitudes of 30 m above mean sea level. The propagation path between the terminals was entirely over water, a distance of 148 km, and transmission frequencies of 52, 100, and 547 MHz were used. Signal levels were recorded for extended periods between June 1944 and July 1945. Plots of the height of the base of the temperature inversion and radio signal levels revealed a striking negative correlation (Fig. 1). Although the existence of a temperature inversion is neither a necessary nor sufficient condition for trapping, temperature inversions are generally associated with a decrease in moisture and the result is often a trapping layer, particularly over the ocean in the southern California area. A convenient parameter in determining the occurrence of ducting is modified refractivity, $M = 77.6 \ (P/T + 4810 \ e/T^2) + 0.157z$, where P is pressure in hPa, T is temperature in Kelvin, e is water vapor pressure in hPa, and z is altitude in m. A decrease of M with increasing altitude is a trapping gradient and the vertical extent of the duct is defined by the top of the trapping layer down to a height where the M value is equal to the M value at the top of the trapping layer, or the surface (Hitney et al., 1985). An analysis of the derivative of M with height shows that rather common values of temperature and moisture gradients in inversions result in a negative gradient of M, or a trapping condition (Kerr, 1951). Fig. 2 shows an idealized tri-linear M-profile where the height of the base of the trapping layer is shown as H_b, the decrease of modified refractivity through the trapping layer is δM, the thickness of the trapping layer is δz, and duct thickness is D. Using a similar refractivity parameter, Hoffman and Gossard (1992) statistically analyzed the effects of H_b, δM, and δz on radio signal level. They found that signal level was correlated with H_b with a coefficient of -0.68; correlations between signal levels and the two other variates were not statistically significant. However, the height of the base of the temperature inversion alone was found to be inadequate for predicting the peak values of maximum signal levels.

Utilizing a recently developed hybrid propagation model called the Radio Physical Optics (RPO) model and taking advantage of the observed correlation, Hitney (1992) demonstrated a capability to assess the height of the base of the trapping layer from observations of the radio signal strength. His method involved using median values of δM, δz, and refractivity gradients below and above the inversion, derived from a set of radiosonde soundings taken in the years from 1969 to 1976 from Point Loma in San Diego, CA. The comparison between Hitney's predictions of trapping layer height, determined from the 1944 radio signals,
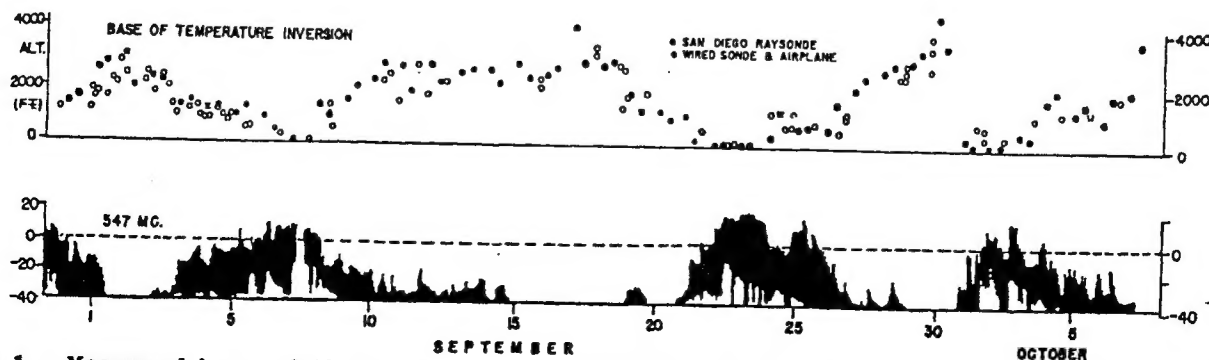

Figure 1. Measured base of the temperature inversion and received signal levels in dB above free space at 547 MHz vs. time for the San Pedro to Point Loma experiment (Anderson, 1944).
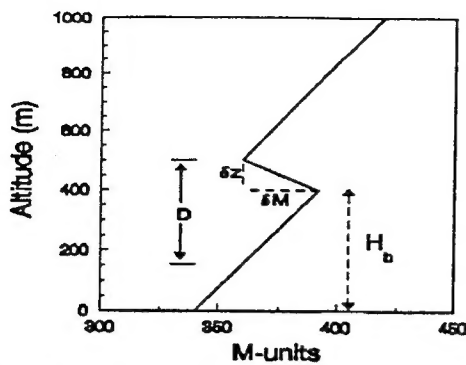
Figure 2. Schematic modified refractivity profile. H_b is height of the base, δM is the decrease of modified refractivity across, and δz is thickness of the trapping layer. D is duct thickness.

and observed base of the temperature inversion was quite good. A proposal was made to pursue this technique further, resulting in the establishment of an experimental program designated Variability of Coastal Atmospheric Refractivity (VOCAR).

EXPERIMENTAL CONSIDERATIONS

The objective of VOCAR is to provide an assessment capability for horizontally varying refractivity conditions in a coastal environment and develop a radio remote sensing capability. Hitney's technique provided the foundation for possible radio remote sensing of refractive structure. Since there are numerous radio sources in coastal areas worldwide, radio remote sensing is potentially a very powerful tool. Among the disadvantages of this technique is that the inferred refractive structure pertains only to the given path and no data exist to indicate how representative this structure would be for different paths. Methods to characterize the horizontal variability of the refractive structure include satellite remote sensing, numerical weather models, and meteorological data assimilation systems. To attack this problem, the Naval Command, Control and Ocean Surveillance Center RDT&E Division conducted an experiment jointly with the Naval Air Warfare Center Weapons Division, Point Mugu, CA, the Naval Research Laboratory (Monterey, CA and Washington, DC), and the Naval Postgraduate School. In addition, the National Oceanic and Atmospheric Administration Environmental Technology Laboratory, Penn State University Applied Research Laboratory, and Johns Hopkins University Applied Physics Laboratory participated in the first measurement phase of VOCAR.

Design of the experiment depended upon expected ducting conditions and the geometry of the propagation links. The southern California bight is ideal for this type of experiment.

Table I. Annual ducting statistics for San Nicolas Is., elevation 153 m.

Surface-based Ducts			
% occur day	39	Duct top (m)	146
% occur night	37	Layer bottom (m)	70
Elevated Ducts			
% occur day	38	Duct top (m)	712
% occur night	39	Duct thickness (m)	160
% occur > one elev duct 5.4		% sfc & elev duct 4.6	

Table I shows on an annual basis that there is a duct present more than 70% of the time at San Nicolas Island (Patterson, 1987), typical of the offshore ocean area. The concave shoreline and the offshore islands are geographically suited for overwater propagation paths. As a proof of concept, a computer-controlled receiver system was setup on Point Loma in San Diego with an antenna at 40 m msl. The aim was to monitor signal strength variations of VHF/UHF transmitters in the southern California coastal region. The Automatic Terminal Information Service (ATIS) transmitters located at many airports provide a variety of propagation path geometries (as suggested by John F. Theisen, private communication). Received signal levels from a number of ATIS transmitters were recorded beginning in September 1991 (Vuong, 1991). Fig. 3 is an example of the data collected for one of the ATIS transmitters at Los Angeles International Airport (LAX).
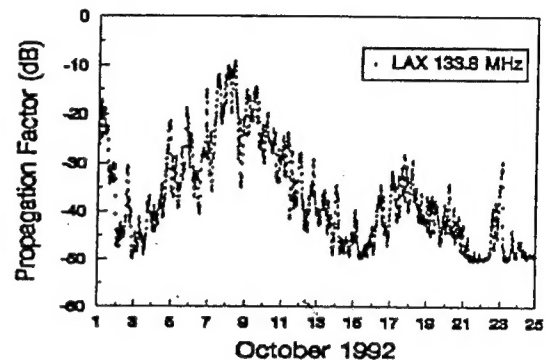

Figure 3. LAX ATIS signal levels measured 177 km away on Point Loma.

Received signal level in dBm was measured every 15 min. The data in Fig. 3 are a weighted average over a two hour period, with weights of 0 at the ends of the window (± 1 hr) and 1 in the center; this averaging has removed the 5 to 10 dB fluctuations that were common on time scales of an hour or two. Like in Fig. 1, 20 to 40 dB variations over scales of a few days are readily apparent in Fig. 3; finer time scale variations of 10 to 20 dB over periods of a few hours to a day are also present as shown in Fig. 4. Similar variations in signal level were observed over other paths. However, the signals received from the San Clemente Island ATIS were not as strong as expected. The scatter diagram in Fig. 5 shows that the ATIS signals from Marine Corps Air Station El Toro were consistently stronger than San Clemente ATIS signals even though the free space propagation loss for these two paths was less than 0.5 dB different. The leading cause for the low signal levels from San Clemente Islands was surmised to be partial terrain obstruction. This conjecture was further supported by the results from a preliminary model capable of representing propagation over both water and varying terrain (Barrios, 1994).
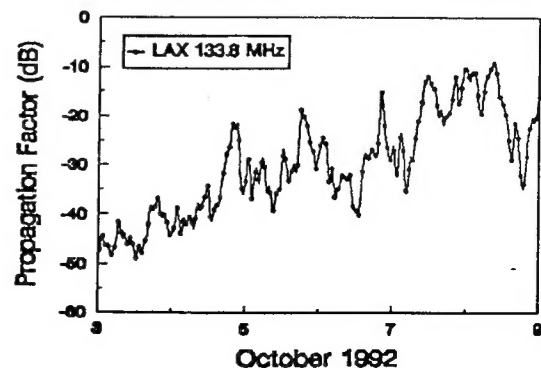

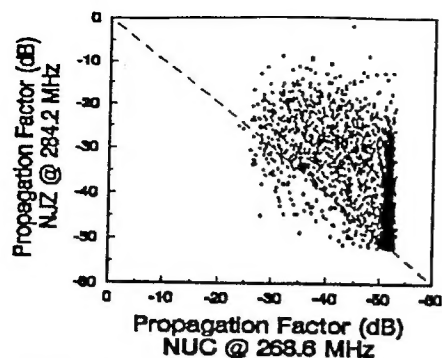**Figure 4.** Propagation factor for a 6-day period in October.

Figure 5. Scatter diagram for Naval Air Facility San Clemente Is. (NUC) and Marine Corps Air Station El Toro (NJZ) ATIS signal levels for period 1-25 October 1992.

September 1993 during which meteorological data were collected by three boundary layer profiler sites, three aircraft, eight radiosonde sites, and numerous surface weather stations. With this data set, propagation predictions using RPO and observed or forecast refractive structure can be compared to observed signals to provide insight to a number of questions, such as the temporal and spatial resolution of meteorological data required to characterize the propagation conditions and the capabilities of different types of sensors to provide such resolution.

SUMMARY

A concept for passively determining refractive structure by monitoring VHF/UHF signal strength variations was discussed and an overview of a cooperative experiment to test this concept was presented.

EXPERIMENTAL DESIGN

With consideration of terrain obstructions, a final experimental design was made. Three additional VHF/UHF transmitters were installed on San Clemente Island at a location that provided clear, over-water paths to the receiver sites at Point Mugu and Point Loma (Fig. 6). These paths are very nearly equal in length and are of primary interest in the experiment. Differences in signals over these two paths will provide data on the inhomogeneity of the refractive structure. Secondarily, paths to ATIS transmitters along the southern California coast will provide information on signal propagation intersecting a coastline. Radio-meteorological data are collected in three categories: routine, special, and intensive observation periods. A routine observation period consists of the radio measurements at two receiver sites and the meteorological data that is routinely available from the existing observing network. A special observation period is a short period of time for which propagation conditions are particularly interesting and a few additional meteorological observations are taken to supplement the routine data. An intensive observation period is an interval during which the VOCAR participants take meteorological observations at a number of sites with a number of sensors in order to characterize the refractive conditions and related atmospheric properties in as much detail as feasible. One such intensive observation period was conducted 23 August to 3

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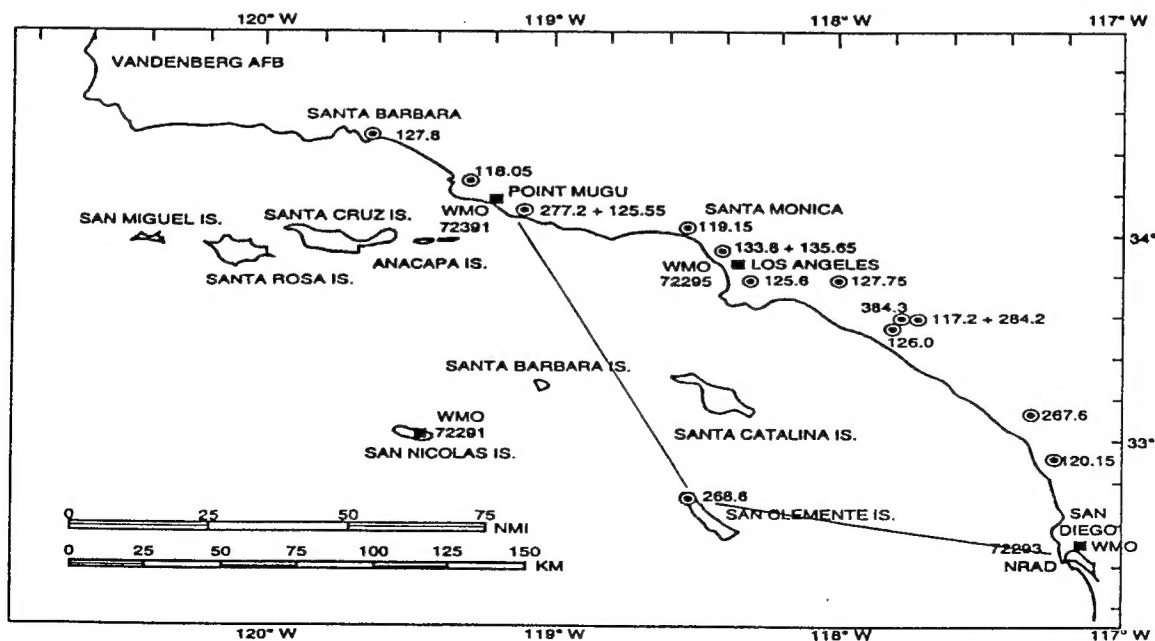Vuong, T.M. "Remote Sensing of Trapping Layer Base Height Using ATIS Transmissions." NOSC TR 1487, 1991.

Figure 6. Selected ATIS transmitters and primary propagation paths for the VOCAR experiment.